Exceptional service in the national interest

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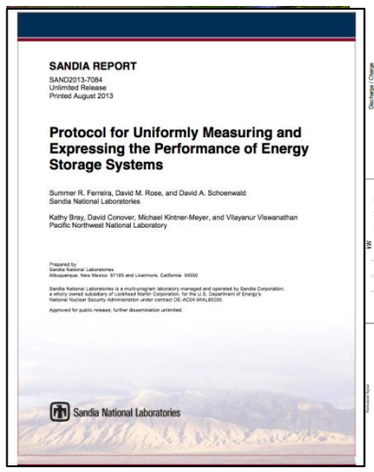

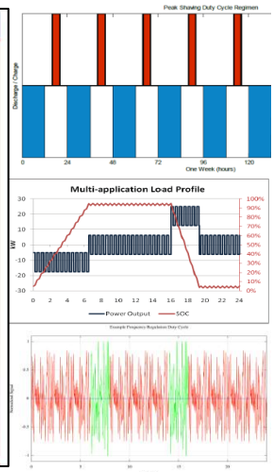

Energy Storage Systems Analysis Laboratory – Cell, Module, and Integrated Systems

9/10/2014 David Rosewater, Summer Ferreira, Ben Schenkman, Josh Lamb, Roy Lopez, Victor Chavez, Wes Baca, Tieshia Francis

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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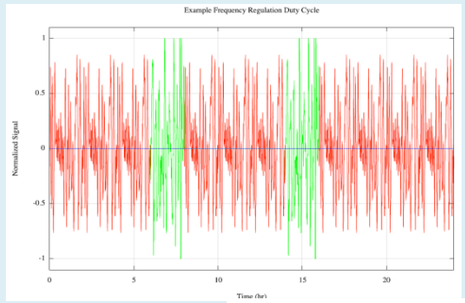
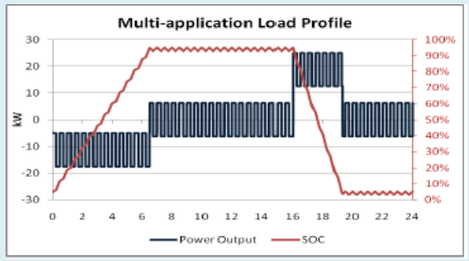
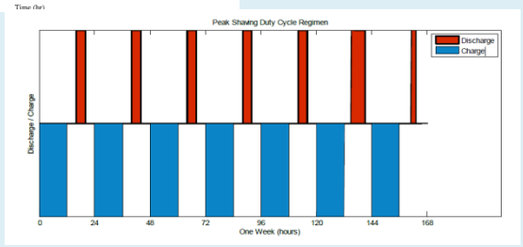
Project Overview:

Development and Application of New Protocols and Analysis Methods







Protocol Development

Cell / Module Analysis

System Analysis

Project Overview: Infrastructure

The Energy Storage Systems Analysis Laboratory (ESSAL)

Providing reliable, independent, third party analysis and verification of advanced energy technologies for cell to MW systems

Cells and Modules

72V 1000A Bitrode (2 Channels)

Cell, Battery and Module Analysis

- **14 channels from 36 V, 25 A to 72 V, 1000 A for battery to module performance analysis**
- **Over 125 channels; 0 V to 10 V, 3 A to 100+ A for cell performance analysis**
- **Potentiostat/galvanostats for spectral impedance**
- **Multimeters, shunts and power supply for high precision testing**
- **Temperature chambers**

Fully Integrated Systems

Lab Analysis

Energy Storage Test Pad (ESTP)

- **Scalable from 5 KW to 1 MW, 480 VAC, 3 phase**
- **1 MW/1 MVAR load bank for either parallel microgrid, or series UPS operations**
- **Subcycle metering in feeder breakers for system identification and transient analysis**
- **Thermal imaging**
- **System Safety Analysis (new)**

Field Analysis (new)

Remote Data Acquisition System (RDAS)

- **Portable, Modular, Remotely Reconfigurable, and outdoor-ready**
- **Subcycle metering**
- **Tractable calibration**
- **Command Signal Ready for Grid Operator Simulation**
- **No control over grid conditions**

Project Overview: Scope (**Jet Analogy**)

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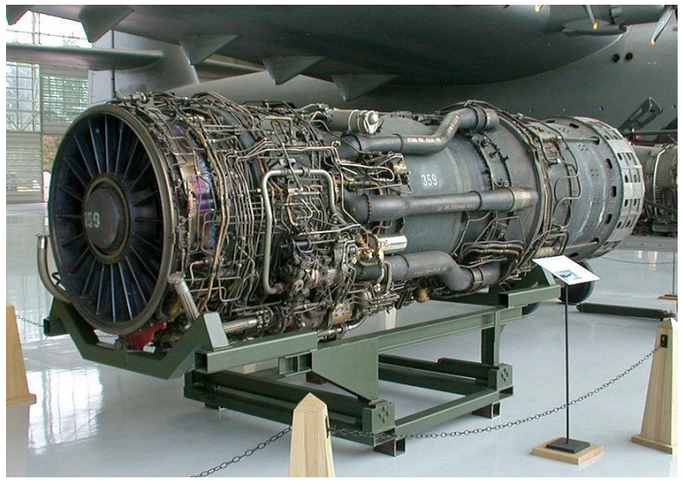
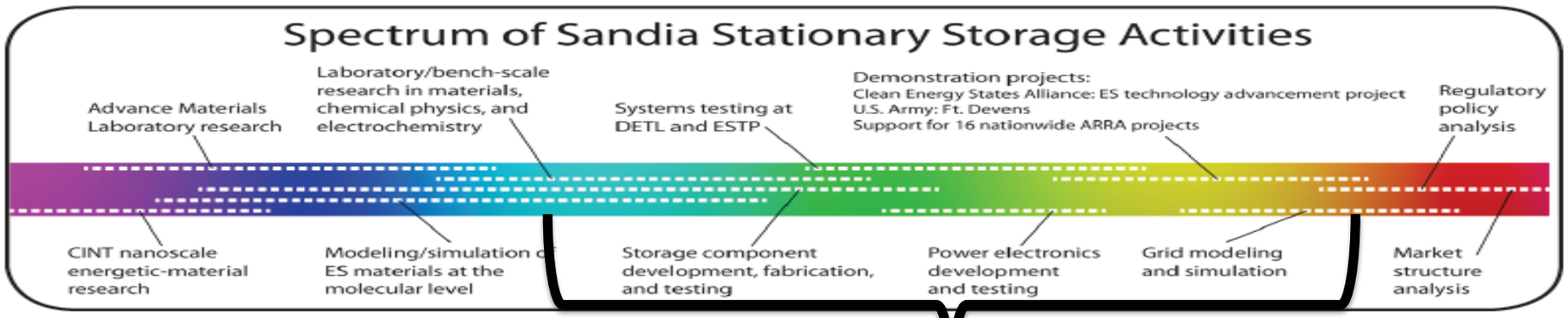
Activity	Cells and Module Analysis	System Laboratory Analysis	Demonstration and Field Analysis
Analogy	 By Greg Goebel [CC-BY-SA-2.0 (http://creativecommons.org/licenses/by-sa/2.0)], via Wikimedia Commons	 By Judson Brohmer/USAF [Public domain], via Wikimedia Commons	 By Aero Icarus from Zürich, Switzerland [CC-BY-SA-2.0 (http://creativecommons.org/licenses/by-sa/2.0)], via Wikimedia Commons
Capability	• Adjustable Environmental Conditions • Control Signals and • Components need to perform reliably	• Adjustable Grid Conditions • Simulated Control Signals • Components need to perform reliably	• Real World Grid and Environmental Conditions • Real World Control Signals • Interconnection Requirements • Maintenance



Range of the ESSAL

Grid Energy Storage System Analysis

- Cell Performance Analysis
  - Altairnano, EnCell
- Pack and String Analysis
  - Aquion, EastPenn
- On-Site System Analysis
  - TransPower, EPC Power, Raytheon
- In-Field System Analysis
  - UniEnergy Technologies (UET)
- Wide Area Control of ESS
  - SunSpec Alliance, MESA, Ideal Power
- Safety Protocol Development
- Stacked Services Degradation Analysis
  - DNV-GL
- DOE Performance Protocol Review

Sandia National Laboratories

Research Partners

altairnano

ENCELL technology

AQUION ENERGY

EASTPENN

TransPower

epcpower excellence in power conversion

UET

Raytheon

IDEAL POWER CONVERTERS

SUNSPEC ALLIANCE

MESA Open Standards for Energy Storage

DNV·GL

Cell Performance Analysis:

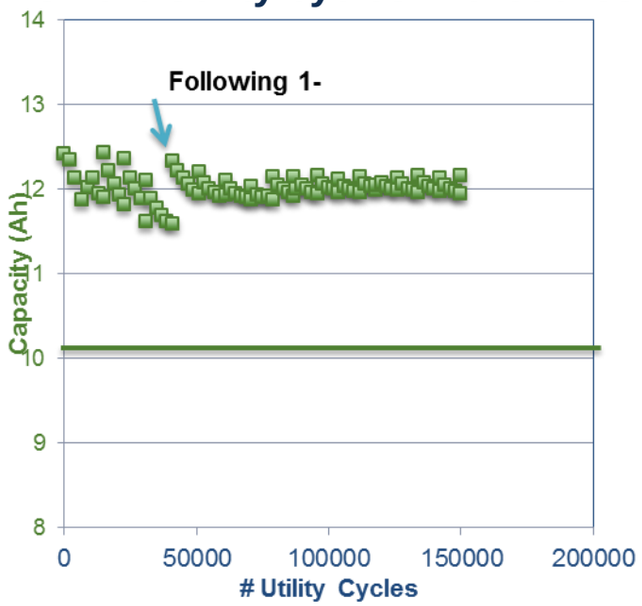
Sandia National Laboratories

Partners: Altairnano, EnCell

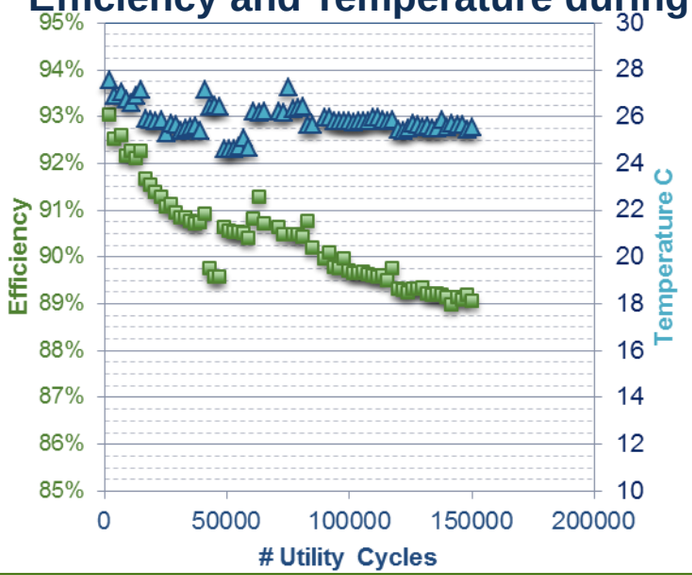
Cycle Life Analysis
11 Ah Altairnano Lithium titanate pouch cell

- 150K+ cycles
- 2% capacity loss
- 5% energy efficiency drop

2C 10% Utility cycles without rests



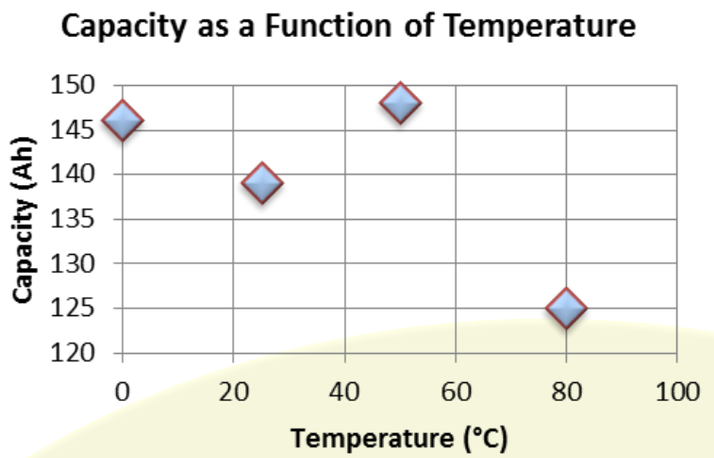
Efficiency and Temperature during Cycling



Encell Alpha Cell Characterization (OE Funded)

Evaluated Alpha design of an Encell rechargeable nickel alkaline battery

- Average capacity of 133 Ah at ambient temperature
- 20% self discharge after 28 days



SAND2014-17462

Office of Electricity support

Applied for testing of Beta design cells

Manufacturer Funded WFO

Evaluated Beta design of an Encell rechargeable nickel alkaline battery

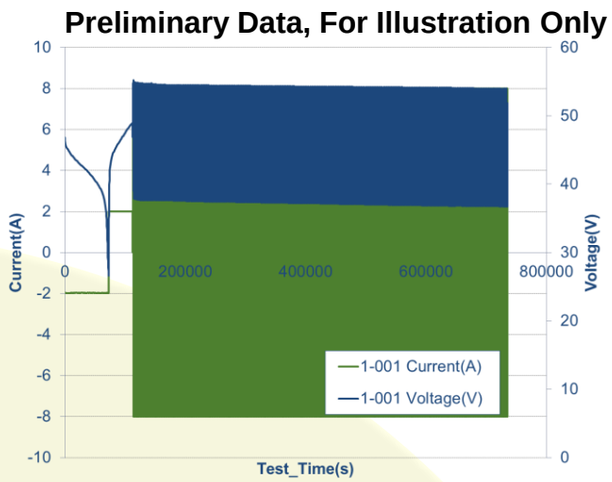
- Average capacity of 139 Ah at ambient temperature
- 10% self discharge after 28 days
- FY ‘14 beta testing to begin for life cycle testing

Longevity and reliability of cell chemistries identified through dedicated lab capabilities can inform resource allocation at the larger scale, especially in established markets such as Li-ion

Pack and String Analysis

Aquion single stack

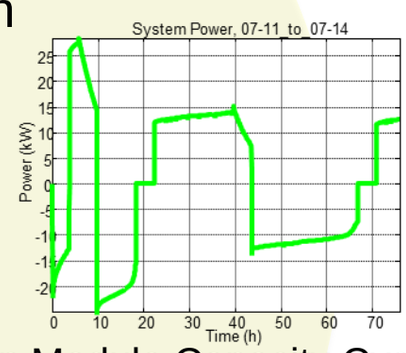
Cycling at Sandia



Aquion Stack PSOC Cycling Data

Supporting analysis of 11 modules

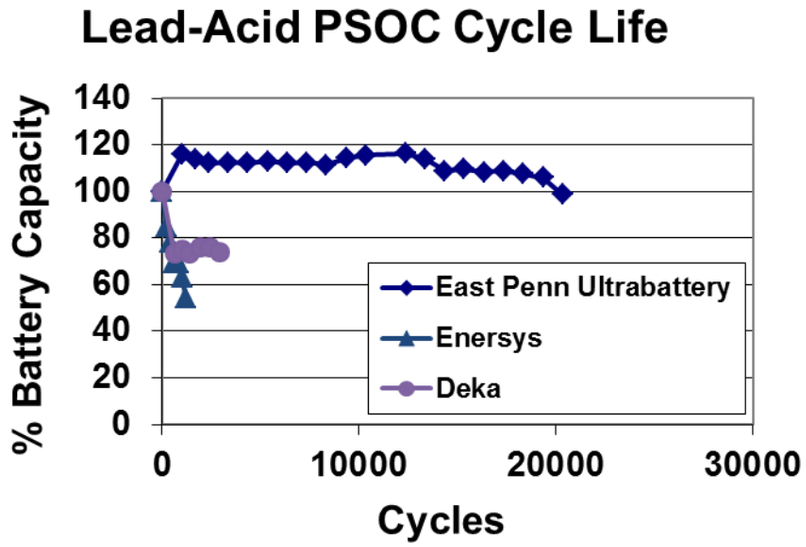
(132 Stacks total) Cycling at Aquion



Aquion Module Capacity Cycling Data

Long term cycling of Aquion begun at Sandia while Aquion designs and tests larger scale systems at their headquarters. Data shared-cycling data can inform design of limits for long term longevity of systems and can inform DOE OE of possible use-cases.

Dramatically longer life in Ultrabattery® Pb-acid compared to more traditional Pb-acid batteries



After a two years of operation in the field we can now compare the laboratory data for power cycling to the demonstration power cycling for this design

Demonstration of the technology through the PNM Prosperity site 0.5 MW/0.35 MWh power smoothing Ultrabatteries

Figure 1: PNM Prosperity energy-storage project.

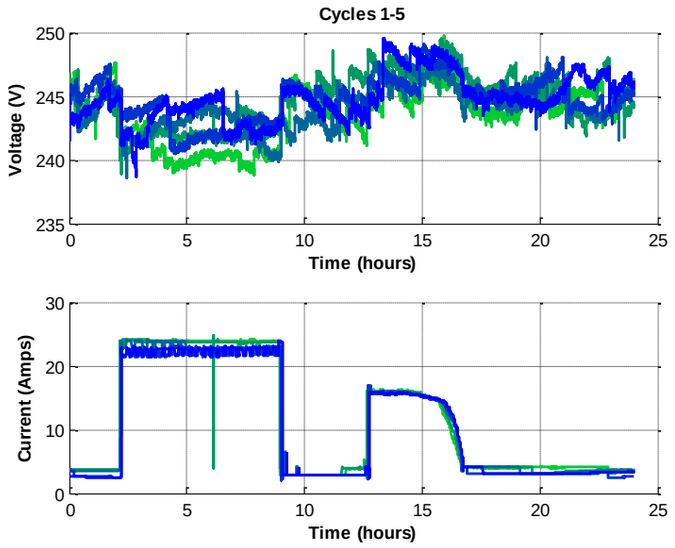
On-Site System Analysis

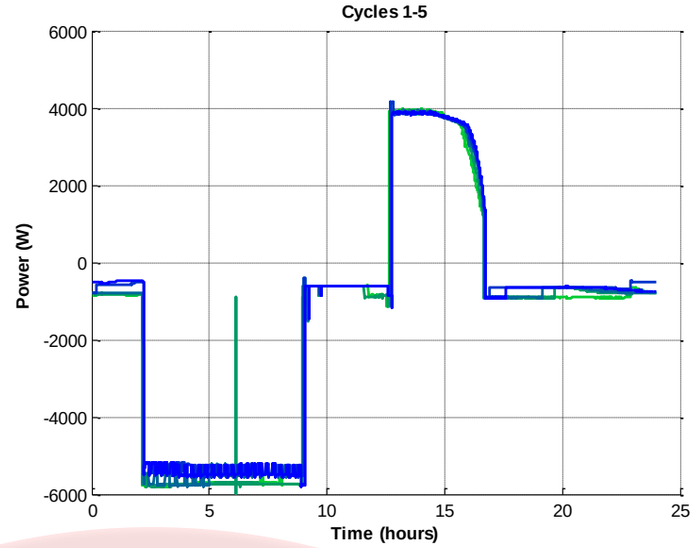
Partner: Raytheon

5kW, 20kWh, Zinc-Bromide Flow Battery System

Installation of the Raytheon RK10 at ESSAL

Preliminary Data, For Illustration Only





Performance Analysis

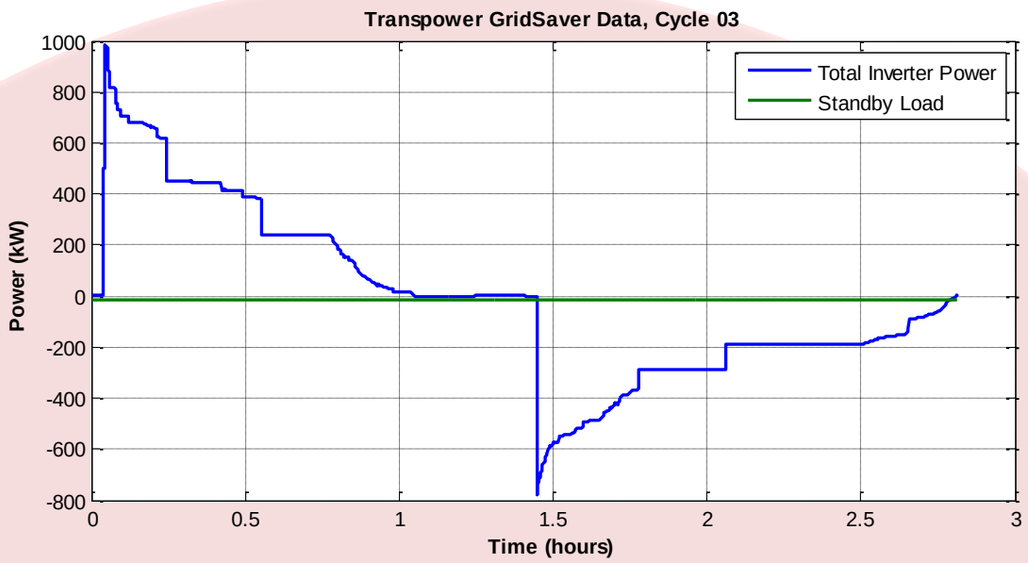
- Capacity (per DOE protocol)
- Peak Shaving (per DOE protocol)
- Power Quality

Project Status

- Accepted Proposal, February 2014
- System Installed, August 2014
- Started Data Collection August 2014
- Data processing in progress

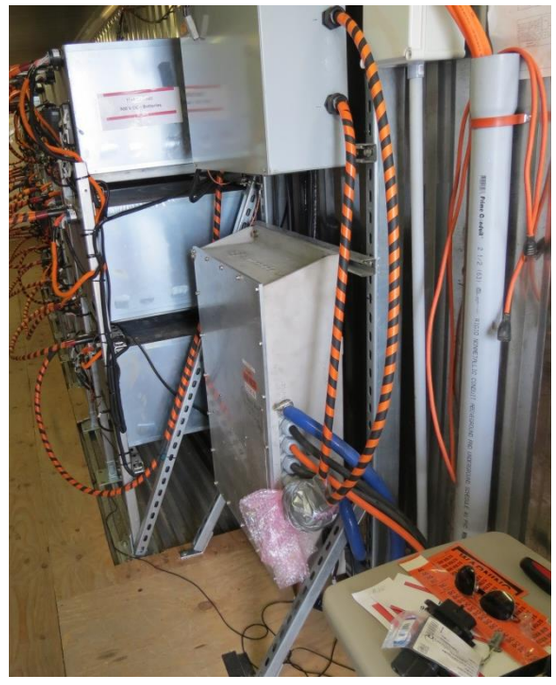
On-Site System Analysis

TransPower: 1MW, 500kWh Lithium-Ion Energy Storage System



Preliminary Data, For Illustration Only

Installation of TransPower Grid Saver at ESSAL



Performance Analysis

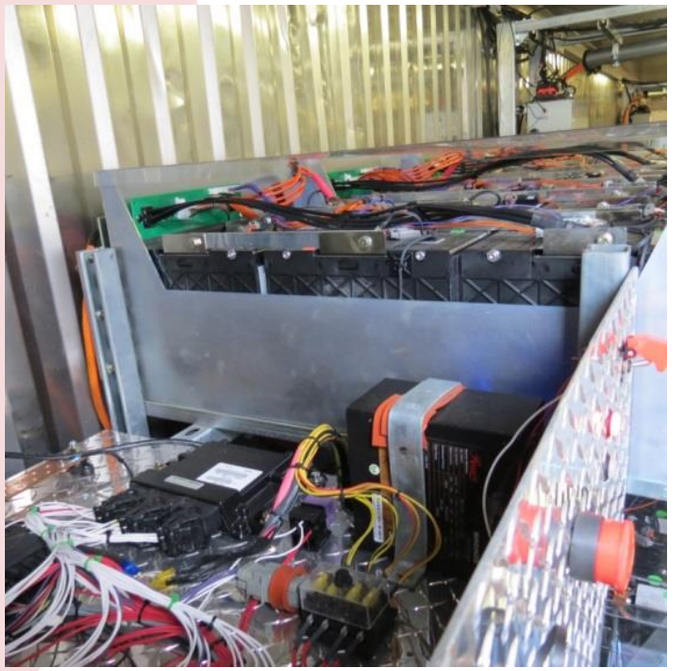
- Capacity (per DOE protocol)
- Regulation (per DOE protocol, 2hr)
- Response Rate (per DOE protocol)
- Power Quality

System Safety Analysis

- Initial Safety Review

Project Status

- Accepted Proposal, February 2014
- System Installed, June 2014
- Initial safety review completed, July 2014
- Started Data Collection August 2014
- Data processing and analysis in progress



String F in GridSaver

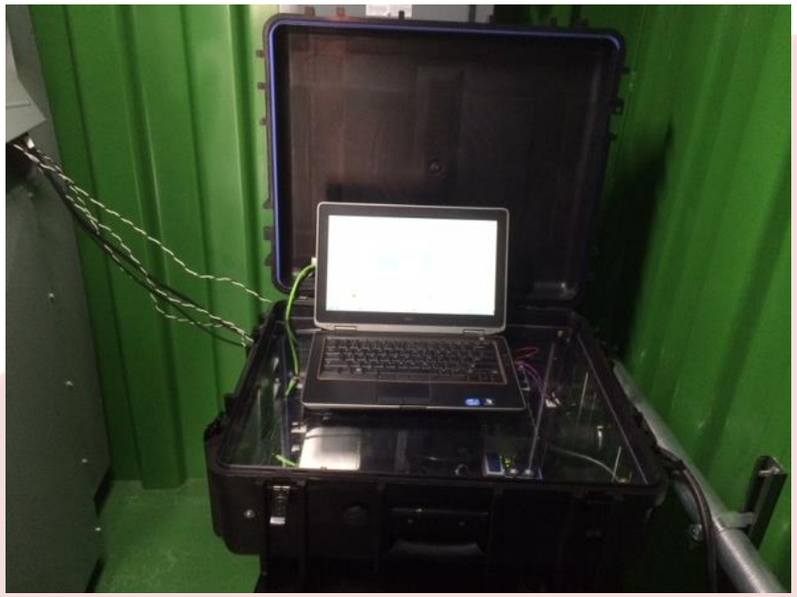
String E (top) and
D (bottom) in GridSaver

In-Field System Analysis

Partner: UniEnergy Technologies (UET)

600kW, 2.2MWh, Vanadium-Redox Flow Battery System

UET system in Washington



RDAS In-Place, Acquiring Data

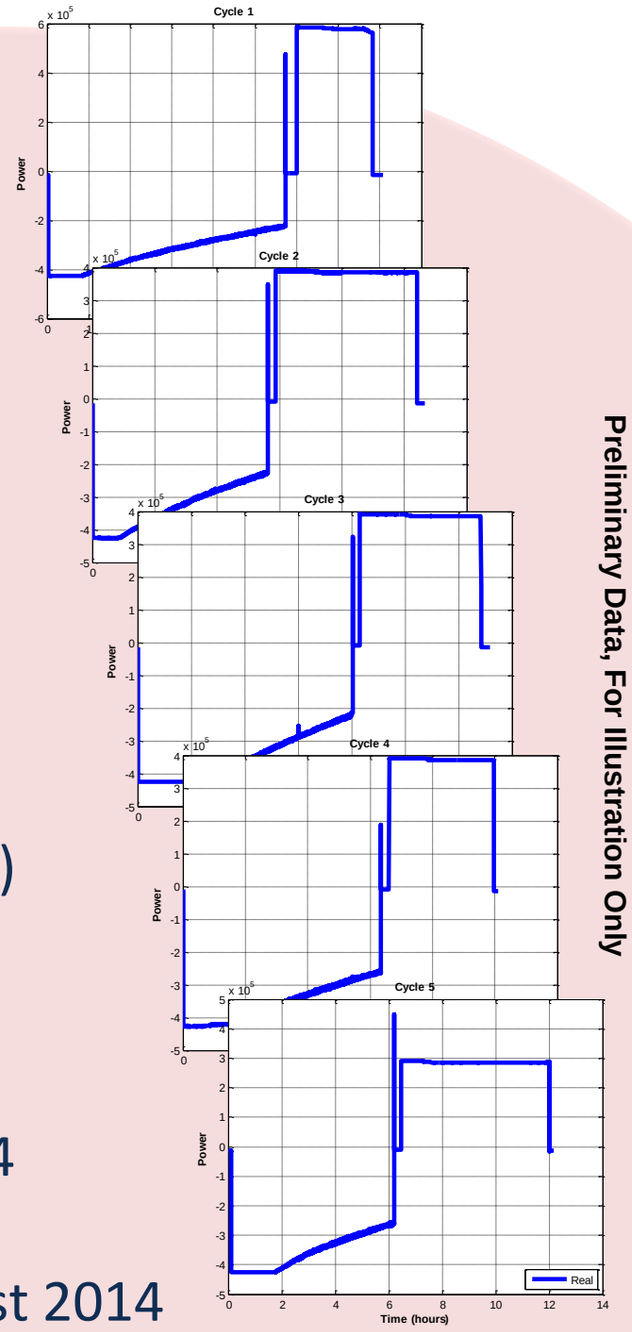
Rick Winter (left), David Rosewater (right)

Performance Analysis

- Capacity (per DOE protocol)
- Regulation (per DOE protocol)
- Peak Shaving (sinewave)
- Power Quality

Project Status

- Accepted Proposal, April 2014
- Installed RDAS, May 2014
- Started Data Collection August 2014
- Data processing in progress



Preliminary Data, For Illustration Only

Wide Area Communication for ESS

Sandia National Laboratories

Partners: SunSpec Alliance, Modular Energy Storage Architecture (MESA), Ideal Power Converters 30kW, Bi-Directional Inverter

Performance Analysis

- Communication interface
  - Interoperability
- Conversion Efficiency
- Power Quality

Project Status

- Inverter Installed, February 2014
- Started Data Collection, March 2014
- Hardware issues incurred delays
- Plan for analysis to restart in FY15

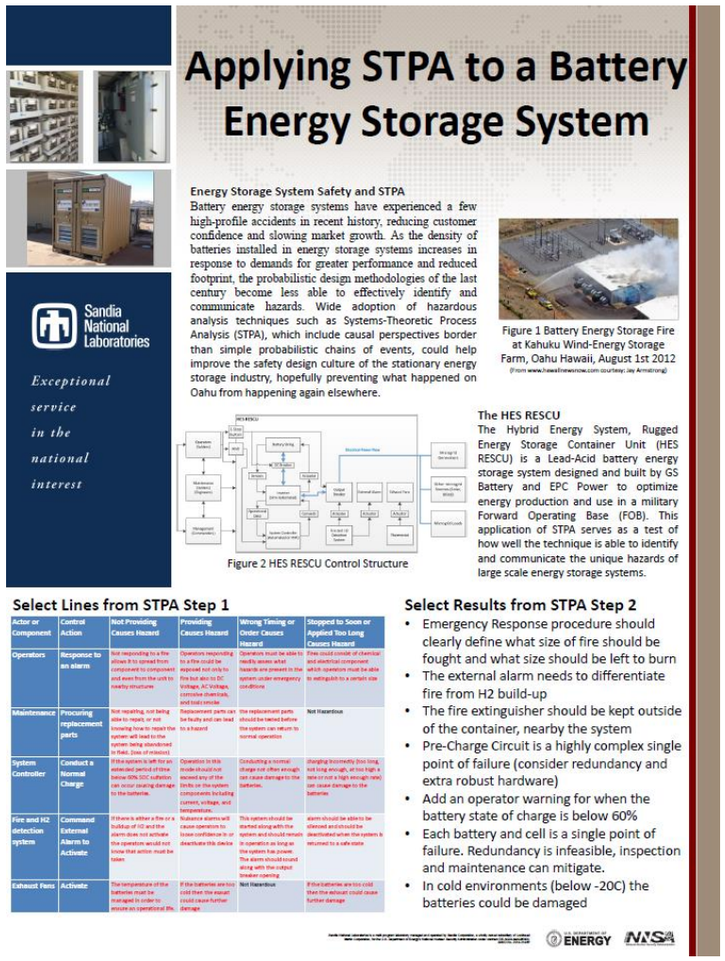
Installation of the IBC-30kW-480 at ESSAL

Safety Protocol Development

Sandia National Laboratories

Safety Engineering Protocols for ESS

- System-Theoretic Accident Model and Processes (STAMP)



SAND2014-2146P
Presented March 2014

Application of Safety Codes and Standards

- NFPA 70 , NEC, Article 480 Storage Batteries
- NFPA 70E Article 320 Safety Requirements Related to Batteries and Battery Rooms
- IEEE Stationary Battery Committee Standards
- IEC 60812 Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)
- IEC 61508 Functional Safety of Electrical /Electronic/ Programmable Electronic Safety-related Systems
- UL and other battery abuse testing standards

Cell Failure Propagation Protocol Development

- Developed stationary battery test procedure to determine if single cell failures will propagate to modules

Project Status

- Poster Presented, March 2014
- System Safety Analisys of TransPower GridSaver is in progress
- Waiting on laboratory availability for module abuse procedure validation

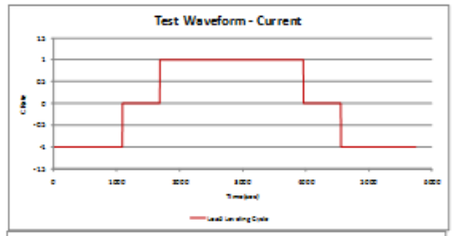
Stacked Services Degradation Analysis

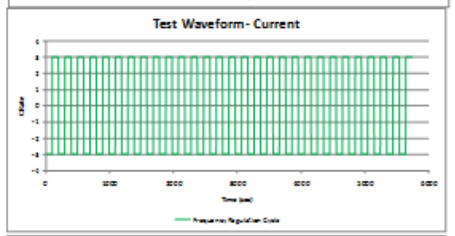
Experimental Design

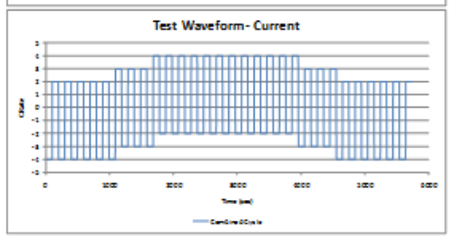
LL Waveform

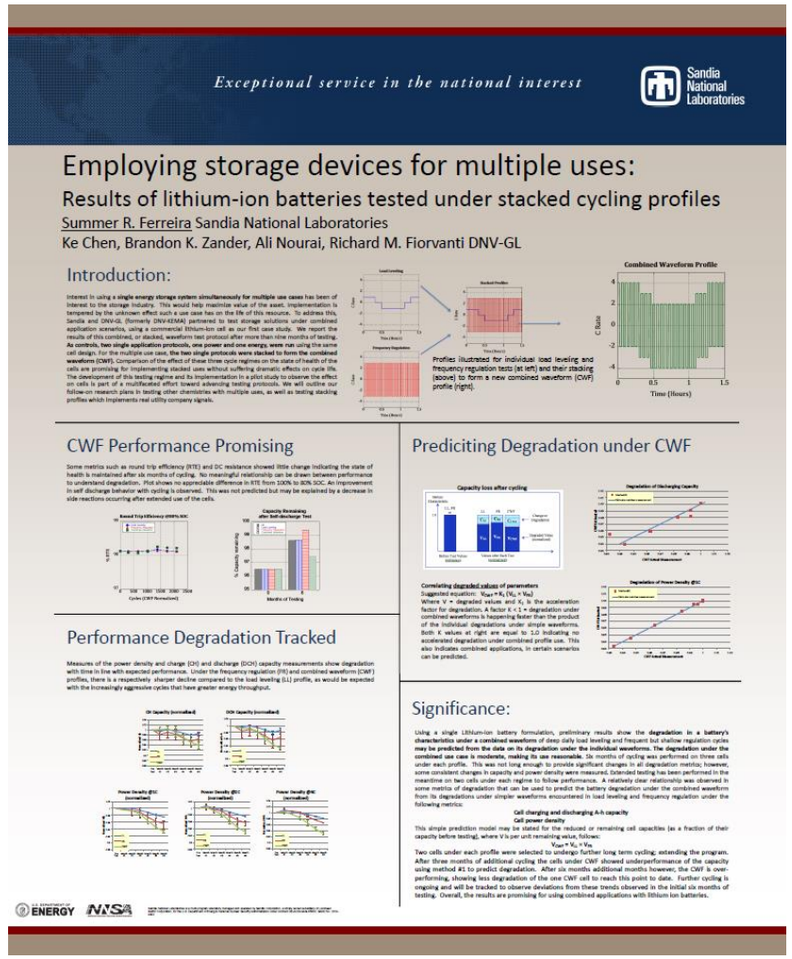
FR Waveform

Combined (CWF) Waveform



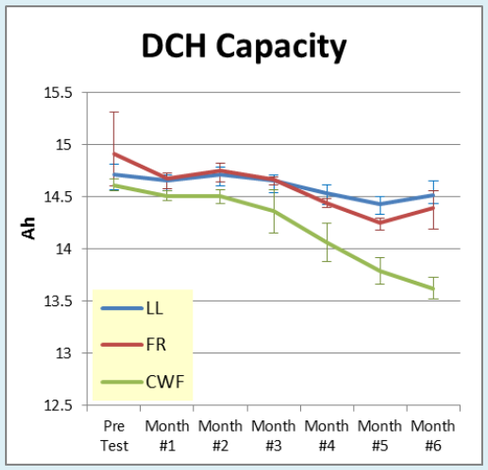


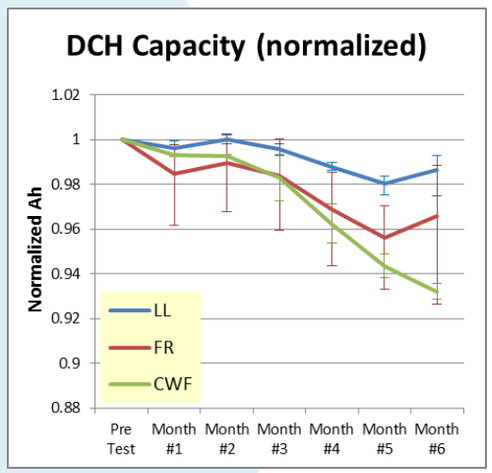




Project Status

- Poster Presented at ESA
- Cells cycling at Sandia
- Planning for implementation on other chemistries and designs
- Planning for implementation of other stacking conventions





SAND2014-4442P
Presented June 2014

In Partnership With

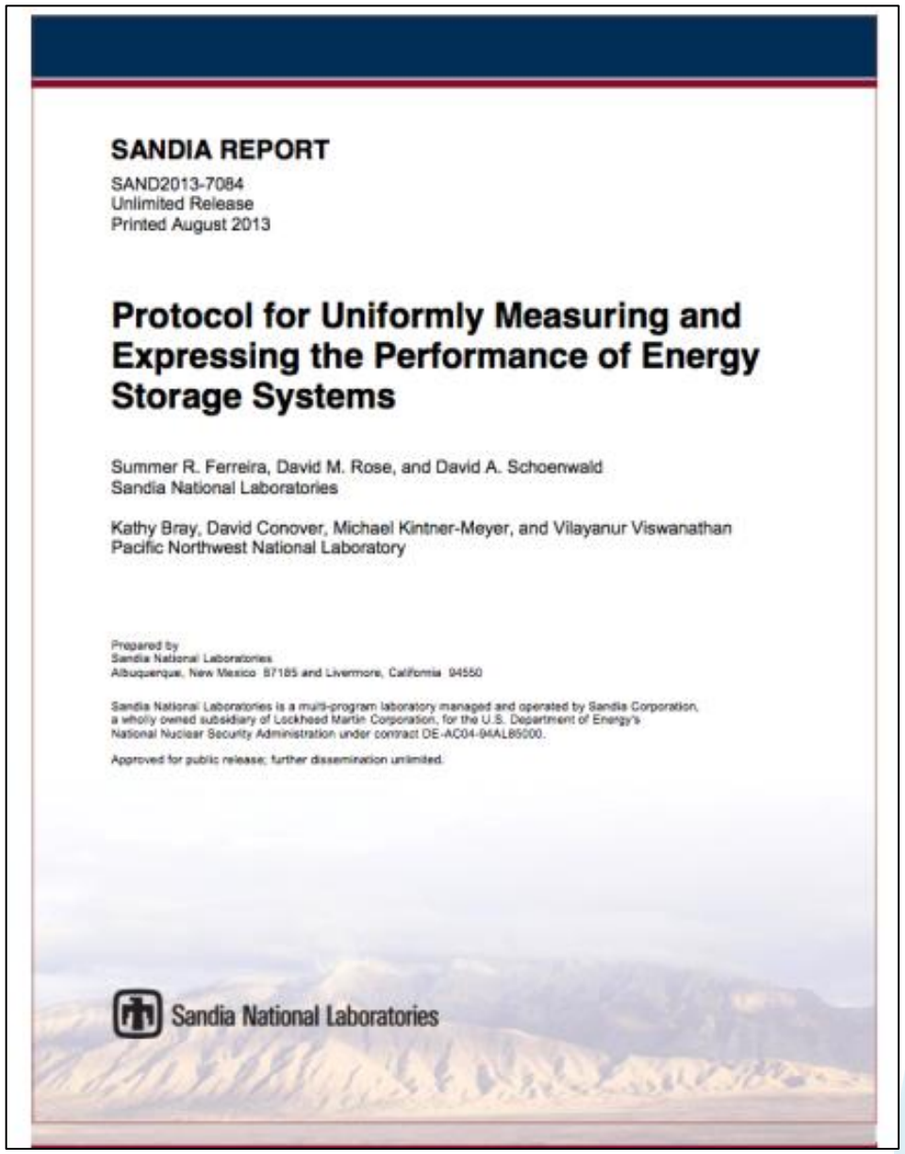
DNV·GL

Summarized Results to Date

Capacity under CWF = (capacity under LL waveform) × (capacity under FR waveform)

DOE Performance Protocol Review

Compulsion of lessons learned from application of DOE performance protocol



SANDIA REPORT

SAND2013-7084
Unlimited Release
Printed August 2013

Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems

Summer R. Ferreira, David M. Rose, and David A. Schoenwald
Sandia National Laboratories

Kathy Bray, David Conover, Michael Kintner-Meyer, and Vilayanur Viswanathan
Pacific Northwest National Laboratory

Prepared by
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Albuquerque, New Mexico 87185 and Livermore, California 94550

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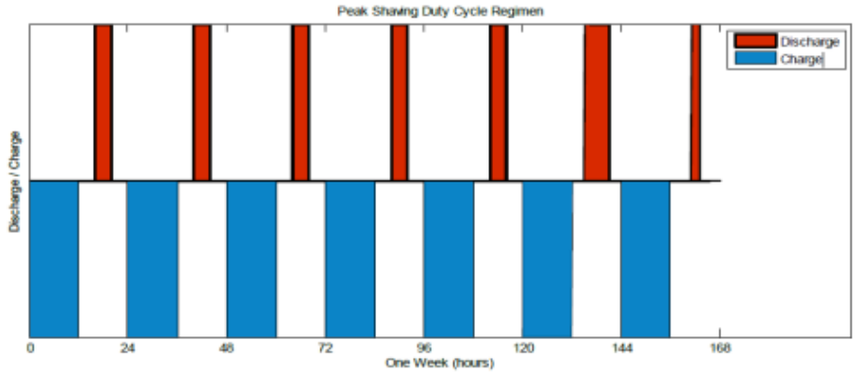
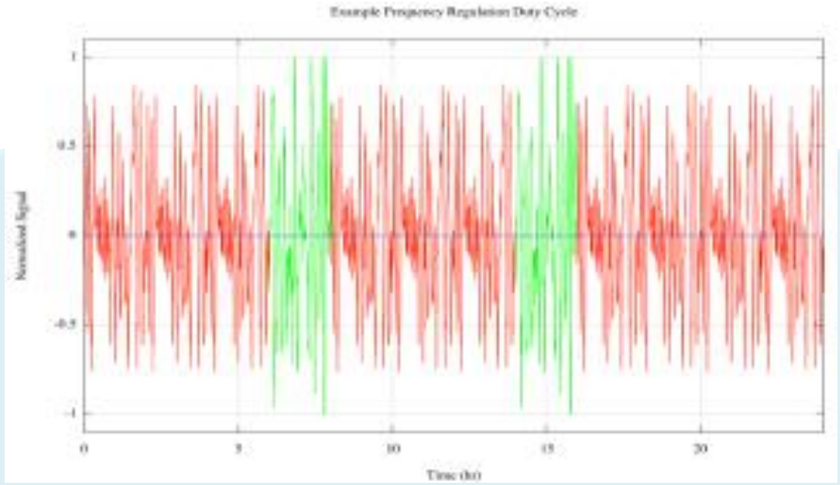




Project Status

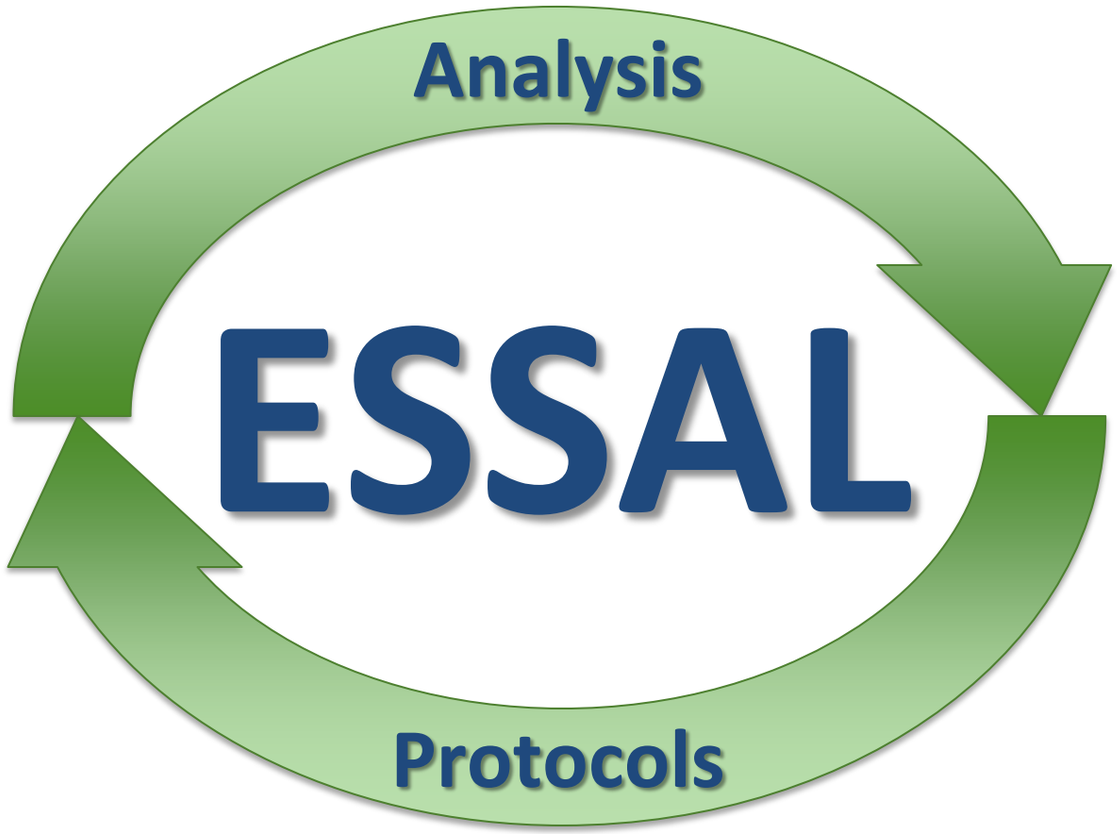
- Data and application notes are being collected
- Working with review committees to add new sections

Summary of FY14 Accomplishments

Sandia National Laboratories

Milestones Reached

1. ESS Safety Analysis Poster Presented
2. Stacked Services Degradation Poster Presented
3. Raytheon RK10 Installed
4. Installed RDAS at UET
5. Multiple Services Poster Presented
6. Aquion Stack on PSOC Cycle
7. TransPower GridSaver Installed



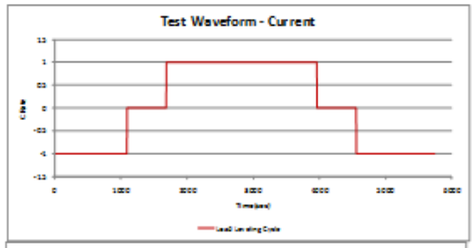
Impact

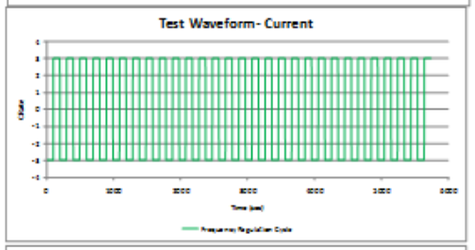
- The next generation of test protocols for energy storage systems will provide better information, at lower cost, then what is now available.
- Data collected and disseminated breaks down the barriers to energy storage acceptance by boosting confidence of customers and regulators
- The technology of research partners can be improved through collaboration
- We are changing how the industry looks at the safety, reliability, and performance of energy storage systems

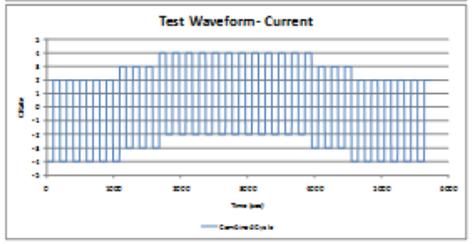
Future Tasks, FY15 and Beyond

Continue to develop new ways of analyzing cell, module, and system performance and safety

- Continue the analysis of UET, TransPower, and Raytheon Systems and expand to other technologies such as flywheels
- Develop robust network of RDAS units and continue to expand safety analysis research
- Expand stacked cell cycle protocol in new next logical dimension
- Develop new safety protocols and analytics







ESSAL Website

www.sandia.gov/batterytesting

The next call for proposals will open soon.

Click to get *FAST-Track* Application

Click to get Standard Application
[more than 6 months]

Click to get Application

Download appropriate application,
Fill out,
Save for your records, and
Email a copy to Energystorage@sandia.gov

Thank You to the DOE OE and especially Dr. Gyuk for his dedication and support to the ES industry and Sandia's ES Program.

Questions?

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